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DOWNWARPING ALONG JOINT PLANES AT THE CLOSE OF THE NIAGARAN AND ACADIAN[1]

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The upper part of the Lockport dolomite exhibits a number of interesting structural features. These are not confined to the Lockport, but many of them have an important bearing on the physical conditions during and immediately succeeding the formation of the Lockport and as such deserve attention. Among the most striking of these are: (1) the huge vase-like residual masses of the Lockport on Flowerpot Island[2] in the Bruce Peninsula of Ontario; (2) the widespread doming of the strata which Kindle has described[3] as probably analogous in origin to the mud lumps at the mouth of the Mississippi; (3) the arching of the strata forming the uppermost or Eramosa beds of the Lockport dolomite in Ontario, where it is ascribed in at least one instance[4] to the presence of an underlying coral reef; (4) the burial of Devonian rock and fossils in joints 18 feet below the present glaciated surface of the Niagara limestone in Illinois;[5] (5) the anticlinal arches which characterize the Lockport in the Niagara region, and which Kindle and Taylor[6] ascribe to local stresses of comparatively recent date; (6) the ripple-mark and other sedimentation phenomena which have been described so frequently;[7] (7) the immediate superposition above the Lockport of the Salina with its salt and gypsum;[8]

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[1] Published by permission of the Deputy Minister of Mines.

[2] Stauffer, *Geol. Surv. of Canada, Guide Book No. 5,* 1913, p. 75.

[3] *Amer. Jour. Sci.*, 4th Ser., XV (1903), 459–68.

[4] Williams, *Geol. Surv. of Canada, Museum Bull. No. 20,* 1915, pp. 1–2. It should be noted, however, that the horizon of the Eramosa beds is below the top of the Lockport as used, for example, by Kindle and Taylor in the Niagara Folio.

[5] Weller, *Jour. Geol.*, VII (1899), 483–88.

[6] *Geol. Atlas of the U.S., U.S. Geol. Survey,* Niagara Folio (No. 190), 1913, p. 109.

[7] Cf. Kindle, *Geol. Mag.*, Dec. 6, I (1914), 158–61.

[8] Cf. Grabau, *Bull. Min. and Metal Soc. Amer.*, VI, No. 2 (1913), 33–44.

and (8) the local downwarping along joint planes, to which this paper is directed.

The downwarping of certain layers near the top of the Lockport dolomite has been the subject of frequent reference, and illustrations of it have been copied and recopied. The structure was first described by Hall, who characterized it as concretionary.[1] Chamberlin and Salisbury[2] first called attention to the fact that the sag is along joint planes, an explanation which is concurred in by Hobbs,[3] but neither of these authors makes any comment regarding the period of deformation. This was first treated by Gilbert in 1905 in a paper of which we have only an abstract. After describing the structures he says[4] that he is not satisfied with Hall's characterization of them as concretionary, but that they were probably contemporaneous with the deposition of the strata and not subsequent to it.

The phenomenon has been described for the following localities: (1) Niagara limestone at Porter's quarry, Niagara Falls;[5] (2) Niagara limestone, Cook's quarry, near Lasalle, Niagara County, New York;[6] (3) Lockport dolomite, Niagara Falls: (*a*) in new railroad cutting; (*b*) in quarry 3 miles east of the city; and (*c*) in water channels temporarily exposed at the Dufferin Islands on the Canadian side;[7] (4) Lockport dolomite, Niagara Falls, old quarry 1½ miles east.[8]

The purpose of this paper is to show that such structures are essentially contemporaneous with the deposition of the strata, that they should be expected to occur where they do, that they are important, and that they have formed under essentially similar conditions in rocks of Cambrian age where the evidence as to their early origin is conclusive.

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[1] *Geol. New York*, Part 4 (1843), p. 94, Fig. 30.

[2] *Geology* (New York: Henry Holt & Co., 1904), I, 150, 151.

[3] *Earth Features and Their Meaning* (New York: Macmillan, 1912), p. 224, legend to Fig. 239.

[4] *Science*, N.S., XXI (1905), 224.

[5] *Geol. New York*, Part 4 (1843), p. 94, Fig. 30.

[6] Chamberlin and Salisbury, *Geology* (New York: Henry Holt & Co., 1904), I, Fig. 137, p. 151.

[7] Gilbert, *Science*, N.S., XXI (1905), 224.

[8] Kindle and Taylor, *Geol. Atlas of the U.S., U.S. Geol. Survey*, Niagara Folio (No. 190), 1913, Illus., III, Pl. XXIV.

In all of the Lockport localities that have been described the warped surface directly underlies till or marine clays. During the field season of 1915 a similar warped surface was discovered to be characteristic of the uppermost beds of the Middle Cambrian in British Columbia. These are dolomites and form the top of the Eldon formation. The basal beds of the Upper Cambrian rest directly upon this warped surface and, as if to yield further confirmation of the fact that the beds forming the top of the Eldon suffered prolonged exposure to the air and that such a condition continued during the period of deposition of the basal beds of the overlying Bosworth formation, the latter is full of mud-cracks, ripple-marks, and casts of salt crystals 2 inches or more in diameter.

The phenomenon was studied in the amphitheater north of Castle Mountain, and there is here no question that the warping was essentially contemporaneous with the deposition of the strata. It is interesting to note that the only known occurrences of this peculiar type of warped structure in both cases occur at the top of a dolomite overlain by shales with salt crystals and evidences of salinity. In the Lockport, Grabau[1] is of the opinion that the overlying Vernon suggests the accumulation of fine loess-like material, chiefly as wind-blown dust. This is of interest in connection with the theory of the eolian origin of the salt deposits of India discussed by Holland and Christie.[2] The bed immediately overlying the warped structure at the top of the Eldon is almost a pure dolomite, and the warped layers whose depressions it fills contain almost as little calcium carbonate. Grabau[3] describes the section between the Lockport and the Salina as composed of a "stratum of thin-layered bituminous accretionary limestone, forming flat, imbricating, shell-like domes" overlain by 2 feet of yellow impure limestone, which is in turn succeeded by the green shale forming the base of the Salina. In this paper on the early Paleozoic Delta deposits of North America, Grabau goes into the physical conditions of Niagara time in great detail, but does not mention the warped surfaces. Likewise Clarke and Ruedemann, in their memoir on the Guelph,[1] do not mention these structures in their discussion of the conditions of life and sedimentation during the prevalence of this fauna. Writers agree, however, that there was a shallowing of the sea near the close of Lockport sedimentation and a gradual increase in its salinity and the magnesian content of its waters. Arguing from the extraordinary thickness of the Guelph molluscan shells, Kindle and Taylor[2] postulate the subjection of the bottom of the Silurian sea at this time to intense wave-action. Calvin[3] accepts the theory which had already been suggested by Hall that "at the close of the Niagara huge mounds and ridges were built on the bottom of the shallow Silurian sea, in part by the accumulation *in situ* of corals, crinoids, and molluscous shells, and in part by the drift of calcareous sediments under strong currents."

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[1] *Bull. Geol. Soc. Amer.*, XXIV (1913), 490.

[2] *Rec. Geol. Survey India,* XXXVIII, Part 2 (1909), 154–86.

[3] *Bull. Geol. Soc. Amer.*, XXIV (1913), 491.

I am inclined to the opinion, and this appears to be corroborated by the position and physical character of the sediments involved, that the sagging of these beds, both those in the Eldon of British Columbia and those in the Lockport of New York, was largely caused by the gentle scour of water at a time soon after deposition. In each case the horizon of the warped structures is the locus of pronounced changes in the paleontologic record. In the Lockport the time was one of a prolonged emergence and marked the close of the Niagaran; in the Eldon it marks the close of the Middle Cambrian or Acadian and doubtless indicates a similar period of emergence at that time. Walcott, who did not, however, have the advantage of having seen the salt crystals of the Bosworth formation, says: "It is difficult to resist the conclusion that the 268 feet of shales forming the base of the Bosworth Upper Cambrian section were deposited in fresh or brackish water or on a river flood plain or delta such as Barrell describes so graphically in his studies of the *Geological Importance of Sedimentation*."[4] The warped structure at the top of the Middle Cambrian in British Columbia has been observed, not only in the Castle Mountain section along the Canadian Pacific Railway, but in the Mount Robson section of the Grand Trunk Pacific 200 miles to the northwest. In each case it is followed by reddish-purple, green, and yellow shales, with ripple-marks, mud-cracks, and casts of salt crystals.

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[1] *New York State Museum, Mem. No. 5* (1903), 114–21.

[2] *Geol. Atlas of the U.S., U.S. Geol. Survey,* Niagara Folio (No. 190), 1914, p. 116.

[3] *Geol. Survey Iowa, Rept.,* 1896, p. 129.

[4] *Problems of American Geology* (Yale, 1915), p. 185.

Salt crystals, previously known only from pre-Cambrian and post-Ordovician rocks, have been assumed, and rightly, to indicate arid conditions and more or less emergence. The peculiar type of downwarping described appears to be the natural result of the quiet subaërial exposure of recently consolidated dolomitic limestones under conditions of aridity. Whether or not the downwarping described is necessarily contemporaneous with aridity, it is certainly a feature due to subaërial exposure, and the probabilities are in favor of its formation at the time of the deposition of the strata rather than subsequently. This necessarily involves the assumption that the joints along whose channels the solution was localized came into existence very soon after the deposition of the strata and were relatively contemporaneous with the deposition of the beds. The evidence as to the early origin of the warped structures is so conclusive that we are justified in disregarding such coincidences as the immediate superposition, where so far discovered, of tills and clays upon the warped Lockport and such inferences as that, since the solution took place along joint planes, it must be comparatively recent. Have we not here rather a slight measure of the duration of the time-break in the deposition between the Middle and Upper Cambrian, and between the Niagaran and the Cayugan, and are we not justified in bearing in mind the principle of relatively contemporaneous consolidation and jointing in rocks?